6.4 Stand Density Measures

STOCKING

1. A loose term for the amount of anything on a given area, particularly in relation to what is considered to be optimum.
2. In a forest, a more or less subjective indication of the number of trees as compared to the desirable number for "best" results.
3. More precisely, a measure of the proportion of an area actually occupied by trees, expressed e.g., in terms of stocked quadrats or percent crown closure, as distinct from their stand density.
4. Adequacy of a given amount of material to meet some management objective. Accordingly, stands can be referred to as "understocked," "fully stocked," or "overstocked." A particular stand that is overstocked for one management objective could be "understocked" for another objective.

STAND DENSITY

1. A quantitative measure of tree stocking expressed either <u>relatively</u> as a coefficient, taking normal numbers, basal area or volume as unity, or <u>absolutely</u>, in terms of number of trees per acre, total basal area, or volume, per unit area.
2. More precisely, a measure of the degree of crowding of trees <u>within stocked areas</u>, -- of crown length to tree height; crown diameter to DBH, or crown diameter to tree height; or of stem spacing to tree height.

Simple indicators of stand density:

- <u>number</u> per unit area (equivalent to "density" in ecological usage)
- <u>basal area</u> per unit area
- <u>crown closure</u> usually expressed as % crown cover (can be obtained easily from aerial photos)

Density indices

- combine a simple density indicator with some measure of avg. tree size
- can be "relative" in nature if an actual stand is compared to a "standard" stand
  - Percent Normality, N% (McArdle, et al. 1930)
  - Stand Density Index, SDI (Reineke 1933)
  - Relative Density Index, RDI (Flewelling 1979)
  - Relative Density, RD (Curtis 1982)
- can be "relative" if a tree dimension is compared to a standard spatial unit
  - Relative Spacing, RS (Wilson 1946)
  - Crown Competition Factor, CCF (Krajicek, et al. 1961)

Percent Normality (N%)

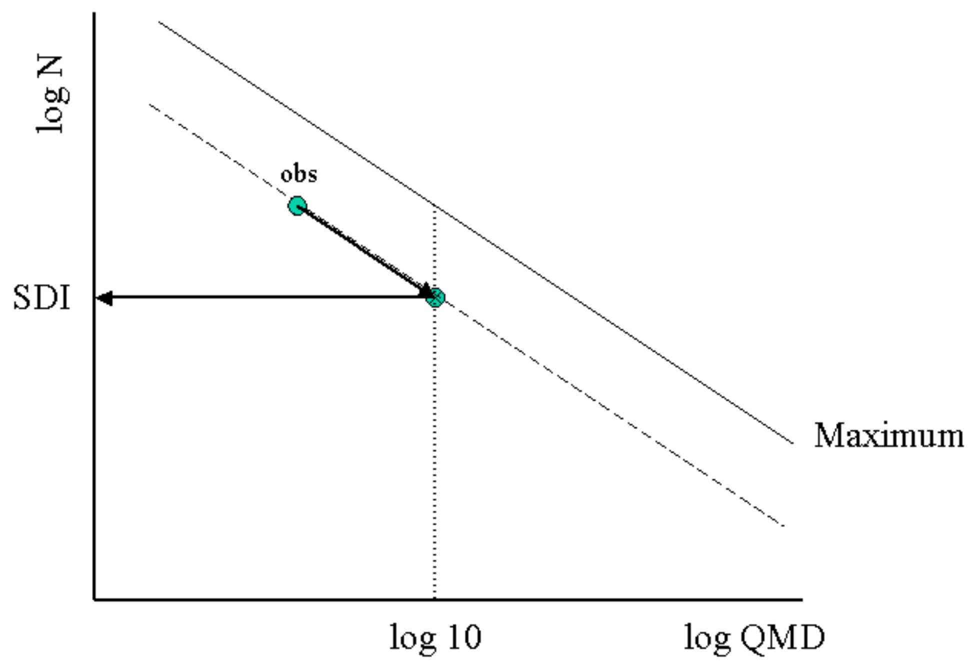
- Based on *Normal* Yield, i.e., the yield that results when the trees are fully occupying the site
- Knowing the age and site index for a particular stand, its basal area can be expressed as a percentage of normal BA for same age and site:

$$N\% = \frac{BA_O}{BA_N}(100)$$

Stand Density Index (SDI)

- Combines number per acre with average tree size, QMD
- Based on a pre-determined limiting relationship between log(QMD)and log(N)
- Expresses density of a stand in terms of an equivalent number of 10-inch trees

$$\ln(N) = \ln(a) - 1.605 \cdot \ln(QMD)$$



- Shortcut formula: $SDI = N\left(\frac{QMD}{10}\right)^{1.605}$
- The exponent 1.605 may vary by species
- SDI increases with either an increase in number of stems per acre or an increase in QMD, or both
- The higher the SDI, the more crowded the stand

Table 2.—*Yield tables for Douglas fir on fully stocked acre, total stand*

TOTAL NUMBER OF TREES

Age (years)	Site Class V		Site Class IV			Site Class III			Site Class II			Site Class I		
	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
20	6,920	5,500	4,150	3,069	2,324	1,815	1,460	1,210	1,012	880	756	654	571	490
30	2,700	2,200	1,800	1,472	1,219	1,030	865	735	640	555	483	408	350	300
40	1,530	1,275	1,090	927	798	680	585	510	445	385	335	282	240	203
50	1,050	890	764	659	572	496	430	377	331	290	248	208	176	150
60	780	670	580	500	439	380	337	296	261	228	195	164	138	116
70	625	537	468	405	352	310	274	242	214	186	160	135	113	95
80	525	455	394	345	303	266	232	207	182	159	136	115	97	81
90	451	398	347	304	266	235	205	180	158	138	118	100	84	71
100	403	352	311	271	239	209	184	161	142	123	106	89	75	64
110	362	319	281	247	217	188	166	146	128	111	95	81	69	58
120	331	292	259	224	197	173	152	134	116	101	87	74	63	53
130	305	271	240	209	184	161	141	124	108	94	80	69	59	49
140	284	252	224	195	171	149	131	115	101	88	75	64	55	45
150	266	238	211	184	160	141	123	108	95	82	71	60	51	42
160	250	225	200	175	152	133	117	102	90	78	67	57	48	40

DIAMETER OF AVERAGE TREE AT BREASTHEIGHT

Age (years)	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
20	1.3	1.5	1.8	2.2	2.6	3.0	3.4	3.8	4.2	4.5	4.9	5.3	5.7	6.2
30	2.6	3.0	3.4	3.9	4.4	4.9	5.5	6.0	6.5	7.0	7.6	8.3	9.0	9.8
40	3.8	4.4	4.9	5.5	6.1	6.8	7.4	8.0	8.7	9.4	10.2	11.2	12.2	13.3
50	4.9	5.6	6.3	7.0	7.7	8.5	9.3	10.1	10.9	11.8	12.8	14.0	15.3	16.7
60	6.0	6.8	7.6	8.5	9.3	10.2	11.1	12.0	12.9	14.0	15.2	16.6	18.2	19.9
70	7.0	7.9	8.8	9.8	10.8	11.8	12.8	13.8	14.8	16.0	17.5	19.1	20.9	22.8
80	7.9	8.9	9.9	10.9	12.0	13.1	14.3	15.4	16.6	17.9	19.6	21.3	23.3	25.5
90	8.7	9.7	10.8	11.9	13.1	14.3	15.6	16.9	18.2	19.6	21.4	23.3	25.6	28.0
100	9.4	10.5	11.6	12.8	14.2	15.5	16.9	18.2	19.7	21.2	23.1	25.1	27.6	30.1
110	10.1	11.3	12.4	13.7	15.2	16.6	18.0	19.5	21.0	22.6	24.6	26.9	29.4	32.2
120	10.7	11.9	13.2	14.6	16.1	17.6	19.1	20.7	22.3	24.0	26.1	28.5	31.1	34.2
130	11.3	12.5	13.9	15.3	16.9	18.5	20.1	21.7	23.5	25.3	27.5	30.0	32.7	36.0
140	11.9	13.1	14.5	16.0	17.7	19.4	21.1	22.8	24.5	26.5	28.8	31.4	34.3	37.8
150	12.4	13.7	15.1	16.7	18.4	20.2	22.0	23.8	25.6	27.7	30.0	32.8	35.8	39.4
160	12.9	14.2	15.7	17.4	19.1	21.0	22.8	24.7	26.6	28.9	31.2	34.1	37.2	41.0

TOTAL BASAL AREA

Age (years)	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
20	64	70	76	81	86	89	92	95	97	98	99	100	101	102
30	96	105	114	122	129	135	140	144	147	150	152	153	154	155
40	121	132	143	153	162	170	177	182	186	189	191	193	195	196
50	140	153	165	177	187	196	204	210	214	217	220	222	224	226
60	154	169	182	195	207	217	226	232	237	241	244	246	248	250
70	166	183	197	211	224	235	244	251	256	260	264	266	268	270
80	177	194	210	224	238	249	259	266	271	276	280	283	285	287
90	185	204	220	235	249	262	272	279	285	290	294	297	299	301
100	193	212	229	245	260	273	283	291	297	302	306	309	312	314
110	200	220	238	254	269	282	292	301	307	313	317	320	323	325
120	206	226	245	261	277	290	301	310	316	322	326	329	332	335
130	213	233	251	268	284	298	309	318	325	331	335	338	341	344
140	218	238	257	275	291	305	317	326	333	338	343	347	350	353
150	223	243	263	281	298	312	324	333	340	346	351	354	357	360
160	227	248	268	287	304	318	331	340	347	353	357	361	364	367

TOTAL YIELD IN CUBIC FEET

Age (years)	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
20	520	620	730	870	990	1,120	1,250	1,380	1,490	1,550	1,650	1,730	1,830	1,920
30	1,330	1,610	1,930	2,270	2,630	2,980	3,300	3,610	3,880	4,110	4,330	4,530	4,750	4,990
40	2,110	2,520	3,020	3,560	4,150	4,690	5,250	5,750	6,160	6,550	6,900	7,220	7,500	7,830
50	2,840	3,410	4,080	4,780	5,540	6,300	7,050	7,730	8,300	8,840	9,320	9,770	10,150	10,560
60	3,500	4,200	5,010	5,880	6,880	7,760	8,700	9,490	10,200	10,860	11,450	12,000	12,500	12,960
70	4,090	4,920	5,820	6,830	8,000	9,100	10,150	11,060	11,900	12,660	13,300	13,950	14,500	15,080
80	4,580	5,510	6,530	7,690	9,000	10,240	11,350	12,400	13,360	14,220	14,990	15,700	16,350	16,970
90	5,000	6,010	7,120	8,400	9,810	11,160	12,390	13,500	14,600	15,540	16,400	17,190	17,880	18,500
100	5,350	6,420	7,620	9,000	10,510	11,940	13,270	14,460	15,600	16,610	17,550	18,370	19,140	19,820
110	5,640	6,780	8,050	9,500	11,080	12,610	14,000	15,290	16,500	17,560	18,510	19,390	20,200	20,940
120	5,900	7,080	8,410	9,920	11,580	13,180	14,600	15,990	17,240	18,340	19,320	20,220	21,090	21,870
130	6,130	7,340	8,720	10,290	12,000	13,650	15,140	16,560	17,870	19,000	20,000	20,980	21,840	22,660
140	6,340	7,600	9,020	10,620	12,370	14,080	15,610	17,090	18,410	19,590	20,640	21,610	22,520	23,360
150	6,520	7,810	9,280	10,920	12,710	14,490	16,080	17,560	18,910	20,130	21,270	22,250	23,170	24,030
160	6,670	8,000	9,500	11,200	13,040	14,850	16,490	18,010	19,380	20,650	21,820	22,830	23,780	24,660

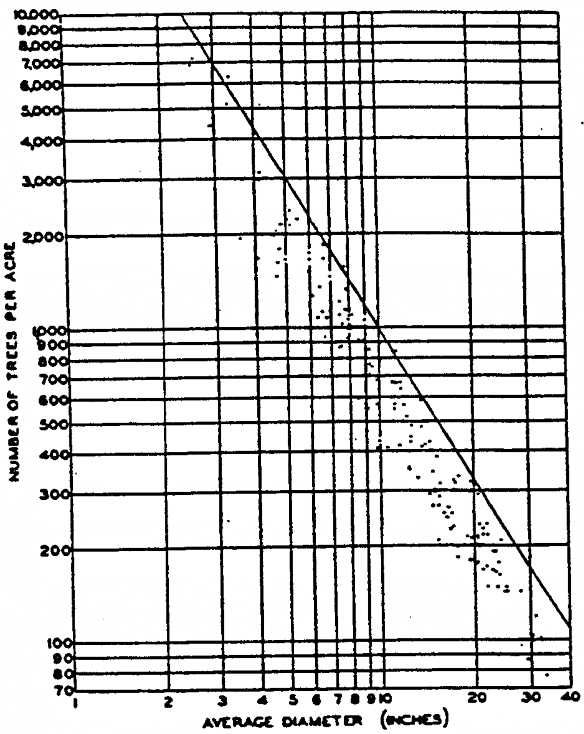


FIGURE 2.—Number of trees—average diameter relation for red fir, with reference curve defining the maxima

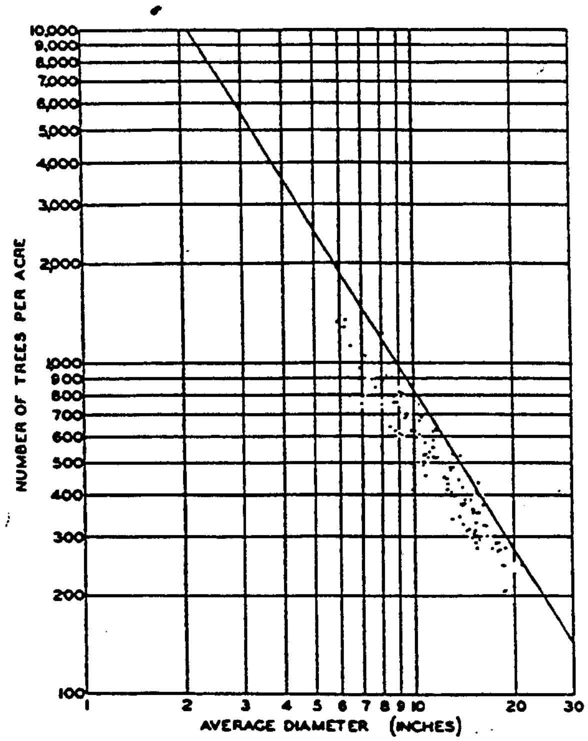


FIGURE 3.—The maximum stand-density index for white fir is 830, as shown by the curve defining the maxima and paralleling the reference curve

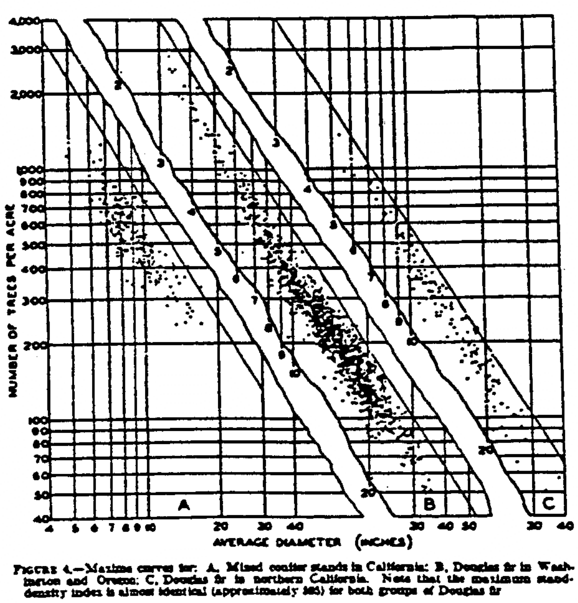


FIGURE 4.—Maxima curves for: A, Mixed conifer stands in California; B, Douglas fir in Washington and Oregon; C, Douglas fir in northern California. Note that the maximum stand-density index is almost identical (approximately 595) for both groups of Douglas fir

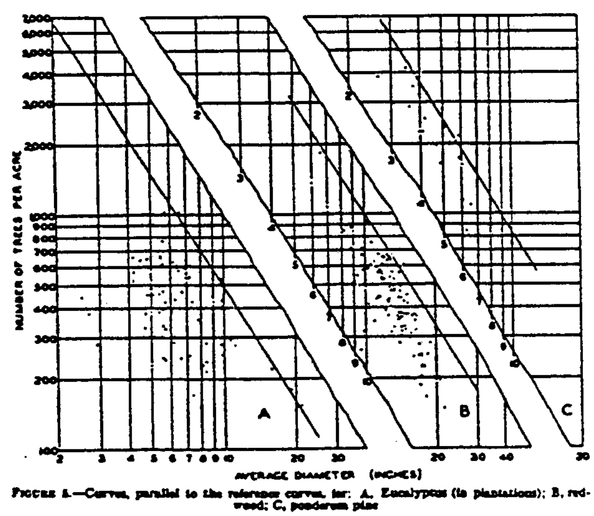
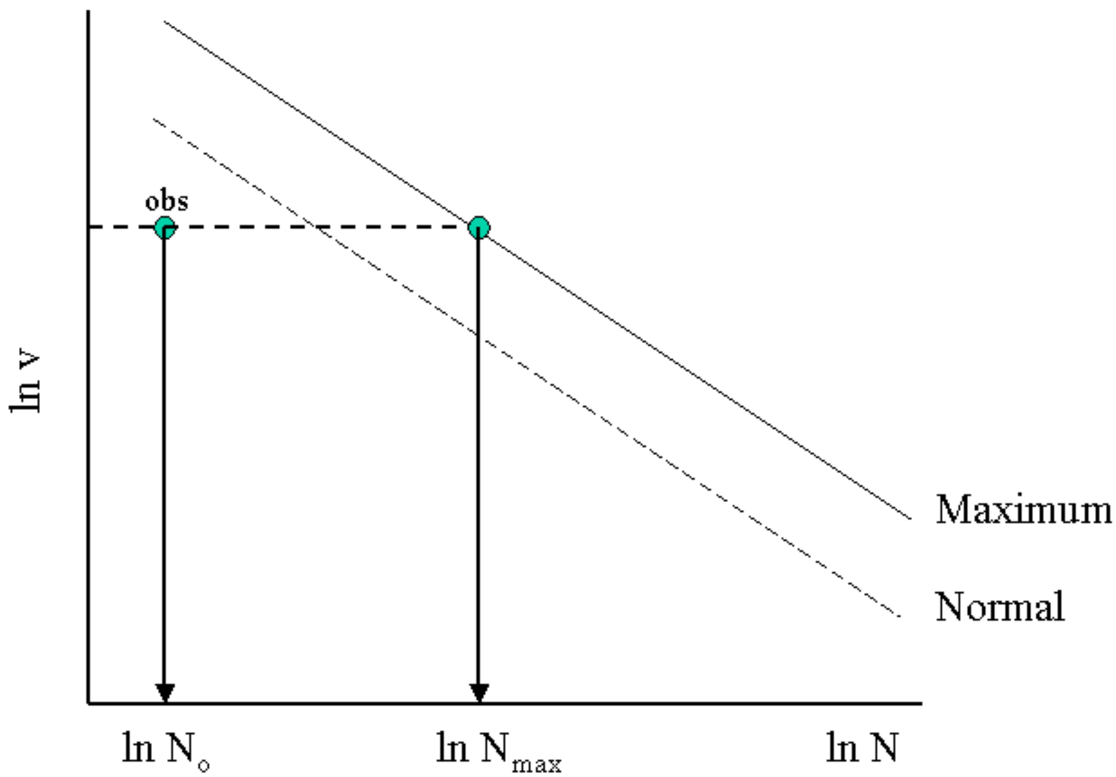


FIGURE 5.—Curves, parallel to the reference curves, for: A, Eucalyptus (in plantations); B, redwood; C, ponderosa pine

Relative Density Index (RDI)

- Combines number per acre with average tree size, volume (cu.ft)
- Based on the – 3/2 power "law" given by:

$$v = aN^{-3/2} \quad \text{or} \quad \ln(v) = \ln(a) - 3/2 \cdot \ln(N)$$



- Relative Density Index, $\rho_r = \frac{N_{obs}}{N_{\max}}$
- $N_{\max} = e^{\left[\frac{12.644 - \ln(v)}{1.5}\right]}$, for Douglas-fir in PNW

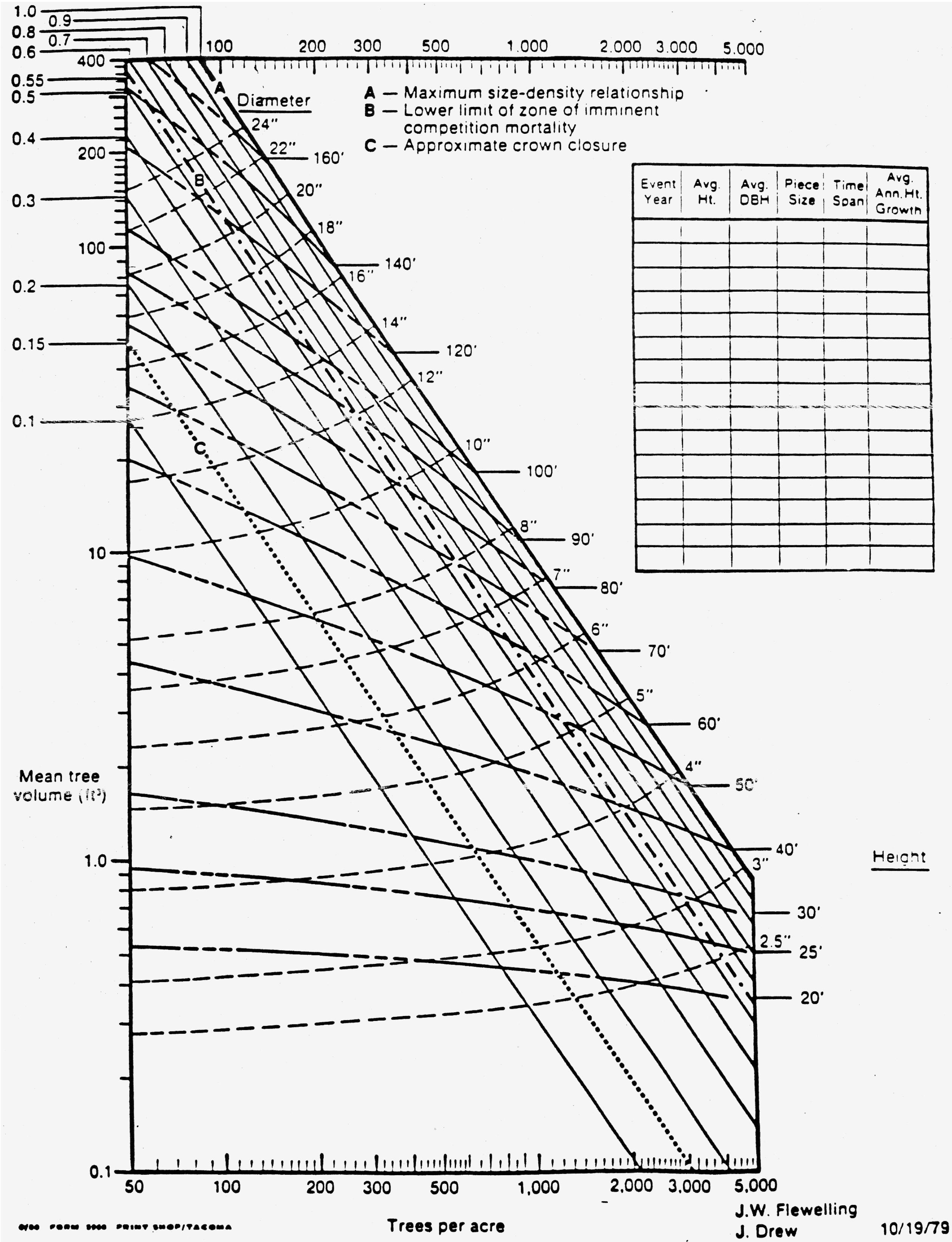


Figure. Density Manamgement Diagram (Flewelling 1979)

Relative Density (RD)

– Combines stand basal area and average tree size, ie., QMD

$RD = \frac{BA}{\sqrt{QMD}}$, where BA is measured in sq.ft/acre, QMD in inches

RD will increase with an increase in BA (with constant QMD)
RD will increase with a decrease in QMD for constant BA
Thus, higher values of RD imply a greater degree of competition

Approximate Relationship Between Selected Stand Density Measures:

Standard	%Normality (BA)	RD (Curtis)	RDI (Flewelling)
Maximum	150	100	1.0
Normal	100	70	0.67
Upper thinning limit	75-80	50	0.5
Lower thinning limit	50 - 60	35	0.3
Crown closure	30	20	0.15

Relative Spacing (RS), or Spacing percent (S%)

Wilson proposed Relative Spacing as a method to assess and control the density of immature conifer stands in the Lake States.

Assuming the trees are either arranged in "regular" or "uniform" fashion or planted using square spacing, the average spacing, S, between trees is then given by

$$S = \sqrt{\frac{43{,}560}{N}}$$

Now, express this as a percentage of average dominant height (H40, say)

$$S\% = \frac{S}{H40}(100)$$

and we have a measure of "crowdedness" of the stand. The more crowded it is, the smaller this number.

Crown Competition Factor (CCF)

- Based on a relationship between open-grown tree crown width, CW (measured in feet) and DBH,

$$CW = a + b \cdot DBH \qquad \text{(for open grown trees)}$$

Then, assuming tree crowns are circular in cross-section

$$\begin{aligned} A &= \pi \bullet r^2 \\ &= \pi \bullet \left(\frac{D}{2}\right)^2 \\ &= \frac{\pi}{4} \bullet CW^2 \\ &= \frac{\pi}{4} \bullet \left(a + b \cdot DBH\right)^2 \\ CA &= k\left(a^2 + 2ab \cdot DBH + b^2 \cdot DBH^2\right) \end{aligned}$$

If there are *N* trees in the stand, the sum of all the crown areas in that stand (if they had been open grown) is then

$$\boxed{\sum CA = k\left(N \cdot a^2 + 2ab\sum DBH + b^2 \sum DBH^2\right)}.$$

We divide this by the area of one acre to put it on a scale such that the sum of CAs = 100 for the hypothetical situation where all crowns are just touching (and thus completely "covering" all ground), giving

$$CCF = \frac{\sum CA}{43{,}560} \bullet (100)$$

So, *CCF* = 100 indicates crown closure; greater numbers indicate competition.

Uses of Relative Density Measures:

1. They are useful descriptors of stand conditions (though not a complete description)
2. They are useful predictors of growth (in combination with other variables)
3. They serve as guides to thinning and stand treatment, by using easily measured stand variables (e.g., RD, or RDI) to define the following–
    a. Upper thinning limit, above which one expects substantial mortality and/or unacceptable diameter growth
    b. Lower thinning limit, below which one expects unacceptable volume growth
    c. Point of crown closure in young stands
4. They can also be used to estimate desirable planting numbers and desirable number of residual trees in pre-commercial thinning (e.g., RD).

$$RD = \frac{BA}{\sqrt{QMD}} = \frac{0.005454 \cdot N \cdot QMD^2}{\sqrt{QMD}} = 0.005454 \cdot N \cdot QMD^{3/2}$$

So, if we specify that RD should not exceed 50 at first commercial thinning (reasonable for Douglas-fir, to avoid suppression mortality and restriction of crown development), then:

$$50 = 0.005454 \cdot N \cdot QMD^{3/2}$$
$$\frac{50}{0.005454 \cdot QMD^{3/2}} = N = \frac{9167}{QMD^{3/2}}$$

For a desired QMD at first commercial thinning, the number to be planted or left after precommercial thinning is N, plus a small mortality allowance E.g., if we desire a 10” QMD at 1^{st} commercial thinning:

$$N = \frac{9167}{10^{3/2}} = 290$$

If we expect, say 3% mortality initially, we might then plant 300 trees per acre.

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